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ENERGY STAR BUILDINGS℠ MANUAL

Stage One
Green Lights

Green Lights Overview

The heat flow diagram (see Figure 1) illustrates how, in Stage One—Green Lights, you can significantly reduce the electrical and cooling loads imposed by your lighting systems. These load reductions will allow you to maximize savings opportunities in your electrical distribution and heating and cooling systems in the subsequent Stages of the ENERGY STAR Buildings[SM] Five-Stage Approach.

Upgrading your lighting in Stage One—Green Lights is the first step in the Five-Stage Approach because:

- Most existing lighting systems have low-risk, highly profitable energy savings upgrade potential
- The changes made to lighting will maximize upgrade opportunities in other building systems
- As the most visible system in your building, successful lighting upgrades foster management and occupant acceptance of other energy-efficiency upgrades

See Figure 1: Heat Flow In Buildings

The Stage One—Green Lights strategy for upgrading lighting systems will not only maximize operation and maintenance (O&M) energy savings but will also improve the visual comfort, safety, and productivity of your occupants and enhance the building's aesthetics and image.

Stage One Strategy

- Design **light quantity** and **quality** tailored to the task and occupants' needs
- Maximize **lamp and ballast efficiency**
- Maximize fixture efficiency
- Use **automatic controls** to turn lights off or down when not needed
- Establish **operation, maintenance, and disposal** practices

A comprehensive approach to lighting upgrades also creates opportunities to improve the efficiency of your electrical distribution and HVAC systems by reducing electrical and cooling loads in the building. These opportunities will be maximized in subsequent Stages Two through Five.

The Best Ways To Save

- Tailor lighting levels to the task and occupants
- Use electronic ballasts for fluorescent lighting where technically compatible with lighting requirements
- Employ automatic controls in all spaces

- Maintain lighting with periodic, scheduled group relamping and fixture cleaning
- Use ENERGY STAR-labeled exit signs

Take Action!

- Challenge the capability of the existing lighting system to meet the current occupant requirements
- Communicate the lighting upgrade's objectives and process to all staff and occupants
- Specify equipment that maximizes *system* efficiency and promotes overall system effectiveness
- Perform trial installations to assess energy use and user acceptance

The Importance Of Lighting

Lighting And The Environment

Lighting consumes a tremendous amount of energy and financial resources. Lighting accounts for 25 percent of the electricity used in the federal sector. The total cost of electricity for the federal government in Fiscal Year 1997 was $3.1 billion. One-quarter of this, $775.5 million, was spent on lighting.

ENERGY STAR Buildings estimates that if new, efficient lighting technologies were used in all federal locations, electricity required for lighting would be cut by 50 percent, electrical demand reduced, and working environments improved. This could save more than $387 million in taxpayer money and result in the following annual pollution reductions:

- 202 million metric tons of carbon dioxide, the primary cause of global climate change. This would be the equivalent of taking 15 million cars off the road
- More than 1.3 million metric tons of sulfur dioxide, which contributes to acid rain
- 600,000 metric tons of nitrogen oxides, which contribute to smog

Table 1 illustrates potential lighting energy savings.

Table 1. Potential Lighting Energy Savings

Lamps and Ballasts	20 to 40 %
New Fixtures	30 to 50 %
Task/Ambient Lighting	40 to 60 %
Outside Lighting	30 to 50 %

Green Lights lighting upgrades save 48 percent of a building's lighting energy use on average.

Source: EPA Green Lights Program.

Lighting And Your O&M Costs

Lighting is also a significant expense in operating buildings. Lighting is the second largest cost component of an office building's electricity bill (see Figure 2) and a significant portion of its total energy bill.

Since 1991, more than 2,500 organizations participating in EPA's Green Light(s) and ENERGY STAR Buildings programs have upgraded more than 1.8 billion square feet of facility lighting and on average have:

- Reduced their lighting energy use by 48 percent
- Invested $0.57 per square foot (sf)
- Achieved a 36 percent internal rate of return

See Figure 2: Lighting Share Of Office Building Electricity Use

Lighting And Your Building

Reduce Heat Gain

In addition to visible light, all lighting systems produce heat. Lighting is typically the largest source of waste heat, often called "heat gain," inside buildings. Improving lighting efficiency reduces heat gain, which affects your buildings in two ways.

First, while waste heat is a useful supplement when the building requires heat, it must be removed by the HVAC system when the building needs to be cooled. The impact of this tradeoff-the penalty for increased heating costs versus the bonus for reduced cooling costs-depends on your building type, its geographic location, and its HVAC system. Although heating costs may rise, they will rarely exceed the resultant cooling savings, even in buildings in northern climates that use electric resistance heat.

Second, by reducing internal heat gain, efficient lighting also reduces your building's cooling requirements. Consequently, your existing cooling system may be able to serve future added loads, or may be appropriate for "rightsizing" in Stages Four and Five. Given the large impact lighting upgrades can have on your HVAC system requirements and the high cost of cooling equipment, you should always quantify HVAC and lighting interactions. There are simplified methods available for calculating the impacts of lighting upgrades on heating and cooling systems. (See *EPRI Lighting Bulletin*, no. 6, April 1994—available through 1-888-STAR YES.)

Improve Power Quality

Lighting also affects the power quality of your building's electrical distribution system. Poor power quality is a concern because it wastes energy, reduces electrical capacity, and can harm equipment and the electrical distribution system itself.

Upgrading to lighting equipment with clean power quality (high power factor and low harmonic distortion) can improve the power quality in your building's electrical system. Furthermore, upgrading with higher efficiency and higher power factor lighting equipment can also free up valuable electrical capacity. This benefit alone may justify the cost of a lighting upgrade.

Lighting And People

A lighting upgrade is an investment not only in reducing electricity consumption but also in improving the performance of the building in supporting its occupants. Next to temperature control, no other building system has as profound an effect on occupant comfort and productivity as lighting. A building's lighting directly affects the comfort, mood, productivity, health, and safety of its occupants. Moreover, as the most visible building system, it also directly affects the aesthetics and image of the building and your business. Successful lighting upgrades take into account the impact of energy-efficiency choices on the building occupants and seek to marry efficiency with improved lighting quality and architectural aesthetics wherever possible. Such a marriage produces “energy-effective” lighting. Energy-effective lighting accomplishes the dual objectives of being energy efficient while also meeting the needs of the space occupants.

Productivity

The relationship of lighting to task performance and visibility is well understood. Improved lighting enhances visual comfort, reduces eye fatigue, and improves performance on visual tasks. Well-designed lighting is likely to improve performance, increase productivity, and reduce absenteeism. Because costs associated with your employees greatly outweigh the other building costs (see Figure 3), any lighting changes that improve your occupants' workspaces have the potential of benefiting both the environment and the economy. Recent estimates place a potential value ranging between $220 million per year and $1.3 billion per year from improved lighting conditions (based on federal salaries).

See Figure 3: Annual Operating Costs Per Square Foot, Typical Office Space

Safety

Lighting also contributes to the safety of occupants and the security of buildings. Emergency lighting must be available during power outages, and minimum levels of light must be available at night when most lighting is turned off. In addition, safety codes require exit signs to highlight escape routes during fires or other emergencies. Outside lighting and indoor night lighting deters crime by exposing intruders' movements and permitting occupants to move safely through the building or to cars.

Although such effects are difficult to quantify, comfort, mood, productivity, health, safety, and other impacts on people should be considered as part of every lighting upgrade.

Green Lights: Maximizing Efficiency, Quality, and Effectiveness

A comprehensive lighting upgrade achieves your qualitative lighting objectives while maximizing efficiency and O&M savings. With rewards beyond the sum of its parts, this process integrates equipment replacement with deliberate design, operation, maintenance, and disposal practices. This whole-system approach takes what is frequently regarded as a complex system of individual decisions and unites them into a strategic approach that ensures that each opportunity is addressed and balanced with other objectives (see Figure 4).

A word of caution: Avoid the temptation to "cream skim" by implementing only the easiest and quickest payback opportunities. While on the surface this may seem appealing, you will forgo many of the systems-interaction and quality-enhancement opportunities that result from aggressive upgrades. Cream-skimming approaches may yield faster payback, but they sacrifice total savings over the useful life of the system.

See Figure 4: Comprehensive Lighting Upgrade Strategy

Table 2 illustrates the economic impacts of pursuing incrementally more aggressive upgrades while maintaining profitability and lighting quality and quantity. (See E SOURCE, *Lighting Technology Atlas*, Ch. 3, pages 44, 45, and 69 for more detail.) ENERGY STAR Buildings ProjectKalc software can help evaluate the energy and economic impact of each component in a comprehensive lighting upgrade.

Table 2. Performance Comparison Of Fluorescent Retrofit Options

	Base case: T–12 Lamps w/magnetic ballasts ***Case 1***	"Energy saving" T–12 lamps ***Case 2***	T–8 lamps, electronic ballasts ***Case 3***	T–8 lamps, electronic ballasts, reflector lens, + 50% delamping ***Case 4***	Same as Case 4 + occupancy sensors ***Case 5***	Same as Case 5 + maintenance ***Case 6***
Avg. maintained footcandles (fc)	28	25	30	27	27	27
Input watts per fixture	184	156.4	120	60	60	50
Total kW	2.208	1.877	1.440	0.720	0.720	0.600
Annual energy use (kWh)	8,832	7,507	5,760	2,880	1,800	1,500
Costs						
Energy savings (%)	N/A	15%	35%	67%	80%	83%
Annual operating cost for energy ($)	883.70	750.74	576.00	288.00	212.40	177.00
Upgrade cost ($)	N/A	312	1,440	1,620	1,970	1,970
Savings						
Energy savings (%)	N/A	15%	35%	67%	80%	83%
Operating cost savings (%)	N/A	15%	35%	67%	76%	80%
Simple payback (years)	N/A	2.4	4.7	2.7	2.9	2.8

Source: Adapted from E SOURCE, *Lighting Technology Atlas*, Table 3.1.

Although every application must be judged separately, some lighting retrofits are generally applicable, especially for aging systems. Most fluorescent lighting systems can be cost-effectively upgraded to T-8 lamps and electronic ballasts. Compact fluorescent lamps (CFLs) are available in a wide range of sizes and wattages, making them good replacements for incandescent lamps, especially where burning hours are long (>4,000/year). Mercury vapor lamps can be replaced with metal halide lamps that are much more efficient. If lighting is left on wastefully in unoccupied spaces, occupancy sensors can eliminate waste effectively.

The first step is to evaluate the existing lighting system by performing a lighting audit. A lighting audit is an accounting of current lighting equipment and controls. It will identify all potential lighting projects or areas that need improvement or may yield energy or resource savings. The aim is an energy-effective, site-specific lighting design.

Lighting Design

Successful lighting design begins with an assessment of the occupants' lighting needs, architectural factors, budget, and other lighting objectives. The lighting system should then be designed to provide the quantity and quality of light responsive to those requirements. Retrofits that skip this assessment may perpetuate designs that have become inadequate because of workspace rearrangements or changing tasks (for example, paper-based to computer-based tasks).

It is important to recognize that people do not see absolute levels of illuminance, the amount of light shining on a surface. They see differences in luminance or brightness-the amount of light reflected back from the surface. The fundamental relationship between lighting and occupant tasks makes it essential that the lighting, task, and surrounding area be evaluated together. Although lighting retrofits are generally limited to the lighting equipment, energy-effective design should evaluate and modify work environments where appropriate. For example, a lighting redesign may reorient computer monitors away from windows or increase the contrast between tasks and their backgrounds.

Room dimensions and finishes also affect the required light output and thus the energy consumption of all interior lighting systems. As much as one-third of the energy use of a lighting system depends upon the surrounding interior features, such as the ceiling height, windows, and color and reflectivity of room surfaces and furnishings. Where possible, the lighting designer should work with both the architect and interior designer to ensure that features that significantly enhance lighting levels, such as large windows and light-colored finishes, are utilized wherever possible. This helps minimize the required light output and therefore the energy consumption of the lighting system.

The Right Quantity Of Light

A common misperception contributing to the proliferation of ineffective and inefficient lighting is that more light equals higher quality light. Lighting-level requirements have evolved with the changes in our workplaces and our knowledge of visual science. The Illuminating Engineering Society of North America (IESNA) has developed consensus-based guidelines to select appropriate illuminance levels for hundreds of indoor and outdoor activities. These recommendations, some of which are listed in Table 3, are starting points, suggesting a range of values based on three criteria:

- The age of the occupants
- The importance of speed and accuracy while performing the task
- The task being performed and the associated background contrast, size of objects, etc.

It is important to note that these are **average maintained** target levels for the task and should not necessarily be applied uniformly as the ambient light level for the entire space. Lighting levels should be customized through the use of supplemental task lighting in areas requiring higher localized levels. Articulated lamps are the preferred option for task lighting for two reasons: they give the occupant the satisfaction of having some control over their environment; and they are very effective in accomplishing task lighting. Target lighting levels should be the sum of the ambient and task lighting levels. This task and ambient lighting design approach creates flexibility to accommodate individual tasks or worker requirements, creates visual interest, and can save considerable energy in comparison to a uniform ambient level approach.

Table 3. How Much Light Is Enough? (footcandles)

Average Reading and Writing	50 fc
Offices with Computer Screens	
Task Lighting	50 fc
Ambient Lighting	25 fc
Hallways	10 fc
Stockroom Storage	30 fc
Loading and Unloading	20 fc
High-Volume Retail	100 fc
Low-Volume Retail	30 fc

Source: *IESNA Lighting Handbook.*

The Right Quality Of Light

Of equal importance to the quantity of light is the quality of light. The quality of light is dependent on both the properties of the light and how that light is delivered to the space. The fundamental quality issues are:

- Glare
- Uniformity of luminance
- Color temperature and color rendition

Remember that the eye does not see absolute levels of illuminance, the amount of light shining on a surface. It sees differences in luminance, the amount of light reflected back from the surface. Eyestrain and fatigue are caused when the eye is forced to adapt continually to different luminances. Therefore, it is important not only to provide the right level of light but also to ensure that light is evenly distributed across the task area. Balancing light levels also ensures that task lighting levels will be adequate throughout the space.

Traditional lighting designs have focused on providing sufficient foot candles (fc) on the horizontal workplane and have generally ignored illumination of the ceilings, walls, partitions, and tasks performed in the vertical. One of the fundamental principles of energy-effective design consists of lighting all of a room’s surfaces, with a heavy emphasis on illuminating its vertical surfaces. Illumination of the horizontal workspace is critical; however, occupants see the vertical surfaces in a room most often. Vertical surfaces have the greatest potential to influence an occupant’s perception of his or her work environment.

Several design options are available which help achieve the right balance:

- Wall washing—the use of fixtures designed to distribute their lighting in one direction and onto a vertical surface
- Indirect lighting—allows wide spacing of fixtures, creating openness
- Direct/indirect lighting—use of luminaires that have both uplight and downlight and are suspended from the ceiling, putting them closer to the workplane and providing better uniformity and fewer shadows
- Cove lighting—used to reduce shadows at upper wall surfaces

IESNA recommends as good design practice an average **luminance ratio** of no more than 3 to 1 for close objects and 10 to 1 for distant objects and outdoor applications (IESNA *Lighting Handbook*, Sect. 15—Office Lighting). In other words, the difference in light level between the task area and the background should be less than a factor of three. While some designers use illuminance variation as an organizing theme, such as defining hallways leading to open offices, or as a highlighting strategy, such as in retail and merchandising locations, large footcandle variations within a workspace should be avoided.

Glare is often cited as the source of visual discomfort in workplaces. Glare results when luminance levels or the differences in luminance levels are too high, and objects appear too bright. Because glare creates discomfort, loss of visual performance, and impaired visibility, it should be minimized wherever possible. Glare generated from a lighting system is most often associated with the misapplication of lamps, reflectors, and louvers, or improperly shielded windows.

The two types of glare you will encounter are direct glare and reflected glare. **Direct glare** occurs when light from a bright object enters the eye directly. It can be controlled through the use of luminaire lenses, louvers, and window blinds, all of which block the direct viewing of sources.

Reflected glare is produced when reflected light creates a shining or veiling reflection, which reduces or washes out task contrast. This commonly occurs on shiny, light-colored surfaces and computer screens. Although veiling reflections are more difficult to control, they can be minimized by: moving the light source, reorienting the task, and installing reflectors, lenses, or louvers on luminaires. Commercially available anti-glare screens also can be attached to computer monitors. Good general practices to minimize glare include the use of lower ambient light levels, task lighting, indirect lighting, and luminaires with a high **visual comfort probability** (VCP) rating. The VCP index provides an indication of the percentage of people in a given space that would find the glare from a fixture to be acceptable. You should ensure a minimum VCP rating of 70 for commercial interiors and 80 for computer areas.

Differences in lamp color can drastically affect a person's perception of his or her environment. The color mix of a light source is described by the terms **color rendering** and **color temperature**. The color temperature of lamps, measured in degrees Kelvin (° K), refers to the relative warmth or coolness of their light color. Cooler lamp colors (4100° K) are very good in applications where high intensity light is needed. Warm lamp colors (<3000° K) are very good in “hospitality” spaces. In most office spaces, intermediate temperature lamps are an appropriate choice (approximately 3500° K) (see Figure 5).

The ability of a light source to accurately reveal the true colors of objects is measured by its color rendering index (CRI), which ranges between 0 and 100 (see Table 4). Lamps with a higher CRI make people and objects appear more natural and bright. Fluorescent lamps with a CRI above 70 are acceptable in most environments.

Table 4. Typical CRI Values For Selected Light Sources

Source	*Typical CRI Value*
Incandescent/Halogen	98+
Fluorescent	
Cool White T–12	62
Warm White T–12	53
High Lumen T–12	73-85
T–8	75-85
T–10	80-85
Compact	80-85
Mercury Vapor (clear/coated)	15/50
Metal Halide (clear/coated)	65/70
High-Pressure Sodium	
Standard	22
Deluxe	65
White HPS	85
Low-Pressure Sodium	0

See Figure 5: Color Temperatures Of Various Light Sources

Maximize Source Efficiency

Too often, lighting retrofits start and finish with the objective of pairing lamps with ballasts to turn electricity into visible light most efficiently. While the majority of energy savings potential often reside here, pursuit of high efficiency alone may lead to compromises in light quality and controllability and higher system installation and maintenance costs. Lamp and ballast specification should seek to optimize efficiency while maintaining a balance with these other considerations.

While a wide range of light sources is available, the predominant types used in commercial and industrial spaces are fluorescent and high-intensity discharge (HID). Historically, fluorescent lighting has been used for high-quality, general-purpose indoor diffuse lighting. HID has been used for industrial and outside lighting. However, recent technology advances and a flood of new products have blurred these general distinctions.

Although fluorescent sources are still limited by their inability to function in very hot or cold environments or as spotlights, advances in physical size, thermal performance, and light quality are allowing wider application in industrial, manufacturing, and residential environments. Likewise, in the past, HIDs have typically been limited by their high light output and their inability to render color accurately or to be switched on and off frequently or dimmed. Today, however, HID lamps are used indoors in some applications where light quality is critical and where dimming and lower light output are necessary. While practical limitations still exist, now, more than ever, specifiers need to research lamp capabilities and understand the tradeoffs between efficiency and performance.

Table 5. Lamp Characteristics

	Standard Incandescent	*Full-Size Fluorescent*	*Mercury Vapor*	*Metal Halide*	*High-Pressure Sodium*
Wattages	3-1,500	4-215	40-1,250	32-2,000	35-1,000
System Efficacy (lm/W)	4-24	49-89	19-43	38-86	22-115
Average Rated Life (hrs)	750-2,000	7,500-24,000	24,000+	6,000-20,000	16,000-24,000
Color Rendering Index	98+	49-85	15-50	65-70	22-85
Life Cycle Cost	High	Low	Moderate	Moderate	Low
Source Optics	Point	Diffuse	Point	Point	Point
Start-to-Full Brightness	immediate	0-5 Seconds	3-9 Minutes	3-5 Minutes	3-4 Minutes
Restrike Time	immediate	immediate	10-20 Minutes	4-20 Minutes	1 Minute
Lumen Maintenance	Good/ Excellent	Fair/ Excellent	Poor/Fair	Good	Good/ Excellent

Ballast selection is integral to lamp performance. All fluorescent and HID lamps require a ballast to provide the necessary starting voltage and regulate lamp current and power quality. Ballasts determine the lamp's light output, life, and control capabilities. Similar to advances in lamp technology, electronics advances have greatly expanded ballast capabilities and selection.

The three types of fluorescent ballasts are magnetic, electronic, and hybrid ballasts. Magnetic ballasts, also known as electromagnetic ballasts, have improved from the standard-efficiency, core-coil ballasts last made in 1989 to higher efficiency models.

Electronic ballasts have been developed for almost all fluorescent lighting applications to replace their conventional magnetic counterparts directly. Electronic ballasts operate fluorescent lamps at a higher frequency, which improves system efficiency by about 30 percent when used in conjunction with T8 lamps to replace T12 lamps and standard magnetic ballasts. Electronic ballasts also offer these advantages:

- Less audible noise and virtually no lamp flicker
- Dimming capability (with specific ballast models)

- Ability to power up to four lamps, increasing energy efficiency by an additional 8 percent, while reducing first cost and maintenance costs

Hybrid ballasts, which combine features of magnetic and electronic ballasts, are also available. Although these ballasts offer the same efficiency benefits as electronic ballasts, they cannot power more than three lamps. Electronic ballasts should always be used, except in the case of technical incompatibility. For example, electronic ballasts should not be used in areas where sensitive electronic equipment is operated.

Instant-start circuitry offers an additional 5 percent efficiency compared with rapid-start electronic ballasts. However, if lamps are frequently switched on and off, additional lamp and maintenance costs may exceed energy savings.

Selecting ballasts for HID lamps involves matching a ballast type to the electrical distribution system in your building to control the lamp light output when line voltage varies. The level of this control is then balanced against ballast losses, power factor, lamp life, and cost. While electronic ballasts are also available for some types of HID lamps, these ballasts are primarily used to minimize size and weight and control lamp color shift. Nominal efficiency improvements of only 5 to 7 percent make retrofits difficult to justify on energy savings alone. However, linear reactor circuit ballasts have been developed which, when used with matched, pulse-start, metal halide lamps, can cut ballast losses in half and offer a 20-percent improvement in efficiency.

Maximize Luminaire Efficiency

A luminaire, or light fixture, is a system of components designed to direct light efficiently while providing a high level of visual comfort (see Figure 6).

See Figure 6: Luminaire Components

Getting a large percentage of light to exit the fixture while controlling its distribution usually requires a compromise. Generally, the most efficient fixtures have the poorest visual comfort. Conversely, fixtures with excellent glare control are the least efficient.

When installing new fixtures, the lighting designer will determine the best compromise between fixture efficiency and visual performance and specify optimized fixtures that fit into the architectural design objectives. When retrofitting fixtures, however, lamps are repositioned, and reflectors and shielding materials are added to balance these objectives.

Reflectors are inserts designed to reduce the internal light loss in fixtures by using highly reflective surfaces to redirect light out of the fixture. They can be used in new fixtures or installed in existing fixtures as part of an energy-savings retrofit strategy. In retrofits, reflectors improve fixture efficiency by improving the internal surface reflectance by up to 17 percent in new fixtures and more if fixture surfaces are old or deteriorating (*see Lighting Upgrade Technologies*, p. 10, EPA 430-B-95-008). By modifying the light distribution of the fixture, reflectors can also facilitate additional energy savings when reducing lighting levels through delamping or relamping.

Reflector performance is largely determined by specific design and installation rather than material selection. As reflector retrofits usually accompany a redesign of lighting quantity and quality in the space, evaluate changes in fixture appearance, target light levels, uniformity, and glare through trial installations.

Most indoor commercial fixtures use some type of diffuser, lens, or louver over the face of the fixture to block direct view of the lamp or to diffuse or redirect light. Although these shielding media improve visual comfort, each one has strengths and weaknesses with regard to visual performance, efficiency, and appearance (see Table 6).

Table 6. Shielding Media Options

Shielding Material	*Luminaire Efficiency Range (%)*	*VCP Range (%)*
Standard Clear Lens	60-80	50-70
Low-Glare Clear Lens	60-80	75-85
Deep-Cell Parabolic Louver	50-90	75-99
Translucent Diffuser	40-60	40-50
White Metal Louver	35-45	65-85
Small-Cell Parabolic Louver	40-65	99

In general, diffusers are simply semitranslucent plastic sheets that hide lamp images and diffuse light evenly across the face of the fixture. Because they spread light in all directions and absorb a large amount of light, diffusers are not only inefficient but also ineffective at controlling glare. By using clear plastic lenses with small prismatic surface patterns instead of diffusers, one can improve efficiency and the distribution of light.

Louver retrofits, depending on cell size and depth, can provide a better balance between superior light control and energy efficiency. Avoid small paracube louvers (cells less than 1 inch) whenever possible; although they provide excellent glare control, they are quite inefficient. Larger “deep cell” louvers provide high efficiency and excellent light control and are available for retrofit into many existing fixtures. New parabolic louvered fixtures are now designed to combine high efficiency (90 percent) with very high VCP ratings above 90. When retrofitting shielding media, evaluate changes in light output, distribution, and fixture appearance using trial installations.

Automatically Control Lighting

Reducing the connected load (wattage) of the lighting system represents only half of the potential for maximizing energy savings. The other half is minimizing the use of that load through automatic controls. Automatic controls switch or dim lighting based on time, occupancy, lighting-level strategies, or a combination of all three. In situations where lighting may be on longer than needed, left on in unoccupied areas, or used when sufficient daylight exists, you should consider installing automatic controls as a supplement or replacement for manual controls. Research has shown that lighting controls have the potential to reduce lighting energy use by up to 35 percent compared with conventional lighting systems without controls.

Time-Based Controls

The most basic controlling strategies involve time-based controls, best suited for spaces where lighting needs are predictable and predetermined. Time-based controls can be used in both indoor and outdoor situations. Common outdoor applications include automatically switching parking lot or security lighting based on the sunset and sunrise times. Typical indoor situations include switching lighting in production, manufacturing, and retail facilities that operate on fixed, predefined operating schedules. Time-based control systems for indoor lighting typically include a manual override option for situations when lighting is needed beyond the scheduled period. Simple equipment, such as mechanical and electronic timeclocks and electromechanical and electronic photocells, can be independent or part of a larger centralized energy-management system.

Occupancy-Based Controls

Occupancy-based strategies are best suited to spaces that have highly variable and unpredictable occupancy patterns. Occupancy or motion sensors are used to detect occupant motion, lighting the space only when it is occupied. The Electric Power Research Institute estimates that occupancy controls can save significant percentages of energy:

- Private offices—25 percent
- Open offices—18 percent
- Conference rooms—35 percent
- Restrooms—40 percent
- Hotel meeting rooms—65 percent.

For both initial and sustained success in using occupancy sensors, the sensor must be able to see the range of motion in the entire space while avoiding either on or off false triggering. This requires proper product selection, positioning, and testing.

Occupancy sensors should first be selected based on the range of body motion expected to occur throughout the entire lighted space. Controls for hallways, for example, need only be sensitive to a person walking down a narrow area, while sensors for offices need to detect smaller upper body motion, such as typing or reaching for a telephone. Once sensitivity and coverage area is established, sensors are selected from two predominant technology types.

Passive infrared sensors detect the motion of heat between vertical and horizontal fan pattern detection zones. This technology requires a direct line of sight and is more sensitive to lateral motion, but it requires larger motion as distance from the sensor increases. The coverage pattern and field of view can also be precisely controlled (see Figure 7). It typically finds its best application in smaller spaces with a direct line of sight, warehouses, and aisles.

See Figure 7: Infrared Sensor Coverage Patterns

Ultrasonic sensors detect movement by sensing disturbances in high-frequency ultrasonic patterns. Because this technology emits ultrasonic waves that are reflected around the room surfaces, it does not require a direct line of sight, is more sensitive to motion toward and away from the sensor, and its sensitivity decreases relative to its distance from the sensor (see Figure 8). It also does not have a definable coverage pattern or field of view. These characteristics make it suitable for use in larger enclosed areas that may have cabinets, shelving, partitions, or other obstructions. If necessary, these technologies can also be combined into one product to improve detection and reduce the likelihood of false on or off triggering.

See Figure 8: Ultrasonic Sensor Coverage Patterns

To achieve cost-effective, user-friendly occupancy sensor installations, both types of technologies need to be carefully commissioned at installation to make sure that their position, time delay, and sensitivity are properly adjusted for the space and tasks.

To ensure proper performance, the position of both wall- and ceiling-mounted sensors needs to be evaluated carefully. Ultrasonic sensors, for example will respond to strong air movement and need to be located away from ventilation diffusers. Infrared sensors should have their line of sight checked to ensure that it is not blocked by room furnishings. Both types of technologies should be positioned and adjusted so that their coverage area is not allowed to stray outside of the intended control area. See Table 7 for appropriate occupancy sensor applications.

Table 7. Occupancy Sensor Applications

Sensor Technology	*Private Office*	*Large Open Office Plan*	*Partitioned Office Plan*	*Conference Room*	*Restroom*	*Closets/ Copy Rooms*	*Hallways & Corridors*	*Warehouse Aisles*
Ultrasonic Wall Switch	✓			✓	✓	✓		
Ultrasonic Ceiling Mount	✓	✓	✓	✓	✓	✓		
Infrared Wall Mount	✓			✓		✓		
Infrared Ceiling Mount	✓	✓	✓	✓		✓		
Ultrasonic Narrow View							✓	
Infrared High-Mount Narrow View							✓	✓
Corner-Mount Wide-View Technology		✓		✓				

All sensors have an adjustable time delay to prevent the lights from switching off when the space is occupied but there is little activity. Some infrared and all ultrasonic sensors also have an adjustable sensitivity setting. Customizing these settings to the application is necessary to balance energy savings with occupant satisfaction.

Although increasing time delays will reduce the possibility of the lighting being switched off while the space is occupied, it will also reduce the energy savings. Setting the sensitivity too high may turn the lighting on when the room is unoccupied, wasting energy. Similarly, setting the sensitivity too low will create occupant complaints, as the lighting may turn off when the room is occupied. Evaluating the potential savings from an occupancy sensor installation should, and can, go beyond guesswork or speculation. Although sensors primarily affect energy use, they also affect energy demand, load on HVAC system, and lamp life. Evaluating the economic feasibility of an installation is best done by monitoring lighting and occupancy patterns. The use of inexpensive loggers will indicate the total amount of time the lights are on when the space is feasibility of an installation is best done by monitoring lighting and occupancy patterns. The use of inexpensive loggers will indicate the total amount of time the lights are on when the space is vacant, the time of day the savings take place, and the frequency of lamp cycling. This information will help you make an informed decision on the economic feasibility of potential occupancy-control opportunities.

Lighting Level-Based Controls

Lighting level-based strategies take advantage of any available daylight and supply only the necessary amount of electric light to provide target lighting levels. In addition to saving energy, lighting level controls can minimize overlighting and glare and help reduce electricity demand charges. The two main strategies for controlling perimeter fixtures in daylighted areas are **daylight switching** or **daylight dimming**.

Daylight switching involves switching fixtures off when the target lighting levels can be achieved by utilizing daylight. To avoid frequent cycling of the lamps and to minimize distraction to occupants, a time delay, provided by a deadband, is necessary. Several levels of switching are commonly used to provide for flexibility and a smooth transition between natural and electric lighting.

Daylight dimming involves continuously varying the electric lighting level to maintain a constant target level of illumination. Dimming systems save energy by dimming fluorescent lights down to as low as 10 to 20 percent of full output, with the added benefit of maintaining consistent lighting levels. Because HID sources cannot be frequently switched on and off, they are instead dimmed for time, occupancy, and lighting level-based control strategies.

Build In An Operations And Maintenance Plan

A lighting upgrade does not end with the installation of efficient equipment. Many cost-effective opportunities for reducing energy and maintenance costs and improving occupant satisfaction are frequently missed simply because operations and maintenance issues are ignored or addressed in an ad hoc fashion after the upgrade. Maintenance is the only way to sustain lighting quality with all of its associated ancillary benefits. The following decisions need to be integrated into your upgrade design from the beginning.
All lighting systems experience a decrease in light output and efficiency over time from four factors:

- Lamp light output decreases (lamp lumen depreciation)
- Dirt accumulates on fixtures and room surfaces (dirt depreciation)
- Lamps burn out
- Luminaire surface depreciation

Over time, these factors can degrade a system's efficiency by up to 60 percent (see Figure 9), wasting energy and maintenance costs and compromising safety, productivity, and building aesthetics. A planned maintenance program of group relamping and fixture cleaning at a scheduled interval minimizes this waste and maximizes system performance.

See Figure 9: Efficiency Loss Over Time

Integrating a planned maintenance program into your lighting upgrade saves money in two ways. First, you will not have to overcompensate with higher initial lighting levels to ensure adequate lighting over time. The lighting system can be rightsized, saving on annual energy use and material first costs.

Second, while replacing lamps as they burn out on a spot basis may seem like a cost-effective practice, it actually wastes valuable labor. Group relamping times the replacement of lamps at their maximum economic value, generally at about 70 percent of their calendar life. Although it means replacing lamps before they expire, group relamping dramatically reduces the time spent replacing each lamp (not to mention the time spent responding to service calls and complaints), which can reduce your overall lighting maintenance budget by more than 25 percent. In addition, planned maintenance reduces the cost of lamps through bulk-purchase discounts, the storage space needs for replacement lamps, and disruptions in the workplace.

To sustain an efficient, high-performance lighting upgrade, assemble an operations and maintenance (O&M) manual. Use it as both the lighting management policy and a central operating reference for building management and maintenance staff. This manual should include the following information:

- Facility blueprints
- Fixture and controls schedule
- Equipment specifications, including product cut sheets
- Equipment and service provider sources and contacts (include utility contacts)
- Fixture cleaning and relamping schedule with service tracking log
- Procedures for relamping, reballasting, and cleaning fixtures
- Procedures for the adjustment of photosensors and occupancy sensors
- Procedures for proper lamp and ballast disposal

Review the O&M manual with the staff responsible for lighting maintenance. Make training mandatory for all new maintenance personnel. Correct operation and maintenance should be built into job descriptions and should become part of all annual performance reviews.

Disposal

A lighting upgrade will most likely require the removal and disposal of lamps and ballasts. Group relamping every several years, and occasional spot relamping as necessary, will also create additional lamp waste. Some of this waste may be hazardous. As the waste generator, you must manage it according to applicable federal, state, and local requirements. While your specific requirements and your selected disposal options will determine the expense, it is important to note that disposal costs are rarely a "deal breaker" in a lighting upgrade. Typically, disposal costs constitute a very small percentage of the overall life-cycle costs of operating a lighting system (see Figure 10). Investigate and budget for these disposal costs both as a first cost during the upgrade and as an ongoing operation and maintenance expense.

See Figure 10: Fluorescent Lamp Life Cycle Cost

All fluorescent and HID lamps contain mercury, which is regulated under the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA)—the Superfund law.

Fluorescent ballasts manufactured through 1979 contain polychlorinated biphenyls (PCBs), the disposal of which is regulated under the Toxic Substances Control Act and CERCLA. Di (2-ethylhexyl) phthalate (DEHP), a substance used to replace PCBs in certain ballast capacitors, is also regulated as a waste under CERCLA. DEHP has been found in ballasts designed for 4-foot fluorescent fixtures manufactured between 1979 and 1985, 8-foot fluorescent fixtures manufactured between 1979 and 1991, and HID fixtures manufactured between 1979 and 1991.

As the generator of these lighting material wastes, you (typically through contractors that install lighting upgrades) are responsible for managing its disposal according to these federal laws and state and local requirements. For a complete explanations of disposal requirements and options, see the ENERGY STAR publication *Lighting Waste Disposal*, EPA 430-B-95-004.

Procurement

It is critical to identify the federal person in charge who will watch carefully over the procurement and installation phase. Very often substitutions will be offered that may not meet the original design intent. It is important to be mindful of this and insist that all products meet the contract specifications and requirements of energy-effective design.

If lighting design assistance becomes necessary, FEMP has developed boilerplate language to obtain additional assistance through a subcontract. The language is available from the FEMP web site and includes a recommended scope of work, evaluation criteria, and general guidance on hiring design professionals.

Both federal supply agencies, the General Services Administration and the Defense Logistics Agency, collaborate with FEMP to provide energy-efficient products that meet operational needs and are cost-effective. FEMP helps buyers purchase efficient products by:

- Identifying Federal supply sources that offer efficient products
- Suggesting ways for buyers to identify efficient products when buying from commercial sources
- Presenting a cost-effectiveness example in order to help the buyer judge whether a price premium is really worth it
- Offering tips to help buyers and users save energy without sacrificing comfort or performance
- Providing leads to other useful sources of information on product energy efficiency

Federal policies mandate the purchase of energy-efficient and cost-effective products (EPAct—Public Law 102-496 of 1992). Agencies are required to “identify and designate those energy efficient products that offer significant potential savings.” Executive Order 12902 (1994) directs agencies to “purchase products listed as energy efficient in the EPAct guidelines whenever they meet the agencies’ specific performance requirements and are cost effective.” Agencies are also to purchase “products that are in the upper 25 percent of energy efficiency for all similar products.”

The 1995 Federal Procurement Challenge also commits 22 federal agencies, representing 95 percent of federal purchasing, to purchase products in the upper quartile of energy efficiency within a comparable class of products.

Commissioning Completed Lighting Improvements

Before a facility is accepted into the federal facility inventory, Executive Order 12902, Section 306(3) requires that each federal agency establish and implement a facility-commissioning program to ensure that new facility construction meets the requirements outlined in the order. While this mandate generally applies to new facilities, the same important principles also should apply to retrofits.

When testing is required as part of the commissioning process, consider using specific lighting tests that may not be part of the standard commissioning test. These tests may involve:

- Light level measurements on work surfaces
- Lighting panel energy measurements
- Relative lighting quality measurements (light distribution, color, reflectance from surfaces, visual comfort probability)
- Lighting control operational measurements, including daylight control sensitivity, occupant sensor sensitivity, and occupant sensor timer

Training

FEMP maintains a locator for energy-efficiency training that includes lighting-related courses, seminars, and workshops. For additional information, contact FEMP at 1-800-DOE-EREC or visit the FEMP web site, www.eren.doe.gov/femp/resources/training/femptraining.html.

FEMP offers a distance-learning course entitled, "Basic Lighting Training." This course is an excellent way to become fully prepared to manage federal lighting projects. The course covers technical lighting knowledge and design, procedural aspects of lighting efficiency projects, ESPCs and evaluation of delivery orders, and life-cycle cost analysis.

Summary

Stage One—Green Lights has described opportunities for saving on energy and O&M costs by upgrading your building's lighting system. Keep the following energy-effective design strategies in mind as you upgrade your lighting system.

- Design **light quantity** and **quality** tailored to the task and occupants' needs
- Maximize **lamp and ballast efficiency**
- Maximize **fixture efficiency**
- Use **automatic controls** to turn lights off or down when not needed
- Establish **operation, maintenance, and disposal** practices

Next Steps

- Assess whether the existing lighting system meets occupant requirements
- Communicate the lighting upgrade's objectives and process to all staff and occupants

- Specify equipment that maximizes *system* efficiency, not just *component* efficiency
- Perform trial installations to assess energy use and user acceptance
- Move forward with lighting upgrades

Glossary

ballast
Power-regulating device that modifies input voltage and controls current to provide the electrical conditions necessary to start and operate gaseous discharge lamps.

carbon dioxide
Colorless, odorless, incombustible gas formed during respiration, combustion, and organic decomposition. Increasing amounts of carbon dioxide in the atmosphere are believed to contribute to the global warming phenomenon.

CERCLA
Comprehensive Environmental Response, Compensation and Liability Act (1980). Also known as the Superfund law.

color rendering index (CRI)
A measure ranging from 1 to 100 of the accuracy with which a light source renders different colors in comparison to natural light, which has a measure of 100.

control
Device that analyzes the difference between an actual process value and a desired process value and brings the actual value closer to the desired value.

CRI
See *color rendering index*.

cycling
The noncontinuous operation of equipment.

deadband
A setting in the lighting control that provides a time delay, signaling the lights to switch off only if the light level is somewhat *above* the setting, or on only if the level is somewhat *below* the setting.

DEHP
Di (2-ethylhexyl) phthalate, an insulator used to replace PCBs in ballast capacitors starting in 1979. DEHP is listed as a hazardous waste in its pure form, but, according to *RCRA*, it is no longer considered hazardous once used in a lighting ballast.

demand charges
Fees levied by a utility company for electric demand.

demand, electric
Electrical power delivered to a system at a given time or averaged over a designated period. Expressed in kilowatts.

diffuser, HVAC
A device that distributes conditioned air to a space.

diffuser, lighting
A device that distributes light produced by lamps into a space.

efficacy
The ratio of lamp lumen output to total lamp power input expressed in lumens per watt.

efficiency
Ratio of power output to power input.

EMS
See *energy management system*.

energy management system (EMS)
The control system that monitors the environment and energy usage in a building and alters equipment operation to conserve energy while providing occupant comfort.

footcandle (fc)
Unit of illuminance equal to 1 lumen per square foot.

heat gain
Waste heat produced during the operation of electrical equipment. Typically, heat gain can be minimized by improving efficiency.

HID
High-intensity discharge.

HVAC
Heating, ventilating, and air-conditioning.

IAQ
Indoor air quality.

IES
Illuminating Engineering Society.

illuminance
Commonly called light level, the light intensity arriving on a surface measured in footcandles.

internal rate of return (IRR)
Compound interest rate at which the total discounted benefits equal total discounted costs for a particular investment.

IRR
See *internal rate of return*.

kilowatt (kW)
Unit of power equal to 1,000 watts.

kilowatt-hour (kWh)
Unit of electric consumption equal to the work done by 1 kilowatt acting for 1 hour.

kW
See *kilowatt*.

kWh
See *kilowatt-hour*.

load
The demand upon the operating resources of a system. In the case of energy loads in buildings, the word generally refers to heating, cooling, and electrical (or demand) loads.

lumen
Unit measurement of the rate at which a light source produces light per unit time.

luminaire
Complete lighting unit, consisting of one or more lamps together with a housing, the optical components to distribute the light from the lamps, and the electrical components (ballast, starters, etc.) necessary to operate the lamps.

luminance
Commonly referred to as brightness, the light leaving a surface measured in footlamberts. It considers both *illuminance* on the surface and reflectance of the surface.

luminance ratio
The ratio between the *luminances* of any two areas in the visual field. This is a measure of the uniformity of luminance.

maintenance
An ongoing process to ensure equipment operates at peak performance.

nitrogen oxides
Chemical compounds that contain nitrogen and oxygen. They react with volatile organic compounds in the presence of heat and sunlight to form ozone and are a major precursor to acid rain.

O&M costs
See *operation and maintenance costs*.

occupancy sensor
A device that detects the presence or absence of occupants and controls operation of equipment accordingly.

operation and maintenance costs
Operation and maintenance costs are material, fuel, and labor costs for routine upkeep, repair and operation of a facility.

packaged unit
A self-contained HVAC unit that provides heating and/or cooling to a building space.

payback
See *payback, simple*.

payback, simple
Also known as *payback*. Measurement of the elapsed time between an initial investment and the point at which accumulated savings are sufficient to offset the initial investment.

PCB
Polychlorinated biphenyl. A substance used as an insulator in the capacitor of fluorescent and HID magnetic ballasts prior to 1970. PCBs have been labeled as carcinogenic and can cause skin, liver, and reproductive disorders.

photocell
A device that responds electrically to the presence of light.

power factor
Ratio of real power to total apparent power.

power quality
The degree to which voltage and current wave forms conform to a sinusoidal shape and are in synchronous phase with one another. Poor power quality can have negative impacts on electrical equipment.

RCRA
Resource Conservation and Recovery Act.

reflector
A device installed in *luminaires* used to direct light from a source via specular or diffuse reflection.

rightsizing
The process of correctly sizing equipment to the peak load.

rooftop unit
Air-handling equipment such as *packaged units* located on the roof.

schedule
A control sequence that turns equipment on and off.

sulfur dioxide
A heavy, colorless, pungent air pollutant formed primarily by the combustion of fossil fuels such as coal. It is a respiratory irritant and a precursor to the formation of acid rain.

VCP
See *visual comfort probability*.

visual comfort probability (VCP)
A rating given to lighting systems expressed as the percentage of people who will be expected to find it acceptable in terms of glare discomfort.

volts, voltage
International system unit of electric potential and electromotive force.

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Figure 1: Heat Flow in Buildings

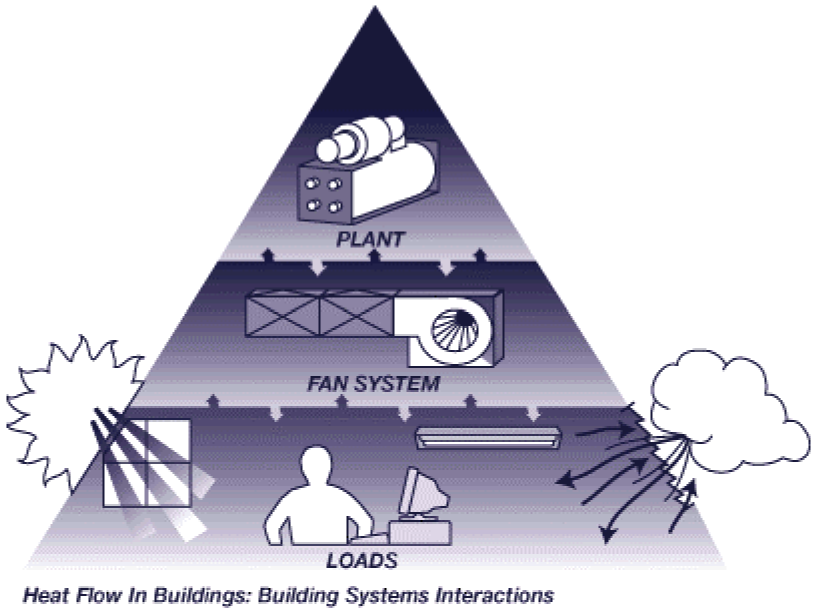

Figure 1 shows the interaction of heating, cooling, and electrical loads with the HVAC equipment. Arrows indicate heat flow pathways. Reducing heating, cooling, and electrical loads reduces the demand on HVAC equipment, thus saving energy.

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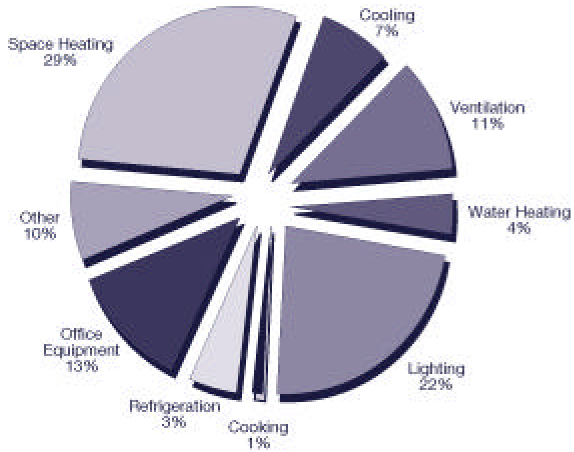
Figure 2: Lighting Share of Office Building Electricity Use



Source: U.S. Department of Energy Information Administration, *Energy End Use Intensities in Commercial Buildings*, Sept. 1994. DOE/EIA-05555(94)/2.

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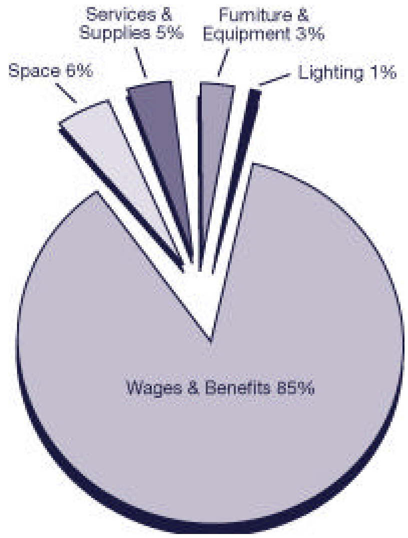
Figure 3: Annual Operating Costs Per Square Foot, Typical Office Space



Source: *Lighting Management Handbook.*

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Figure 4: Comprehensive Lighting Upgrade Strategy

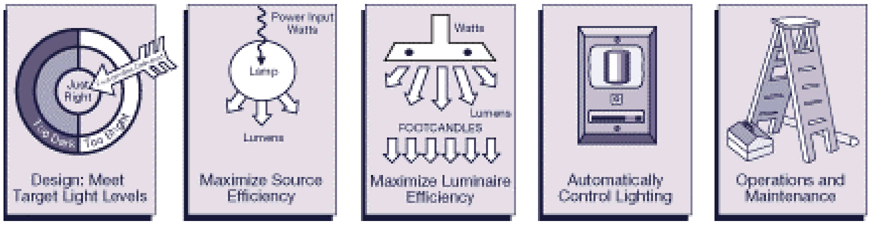

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Figure 5: Color Temperatures Of Various Light Sources

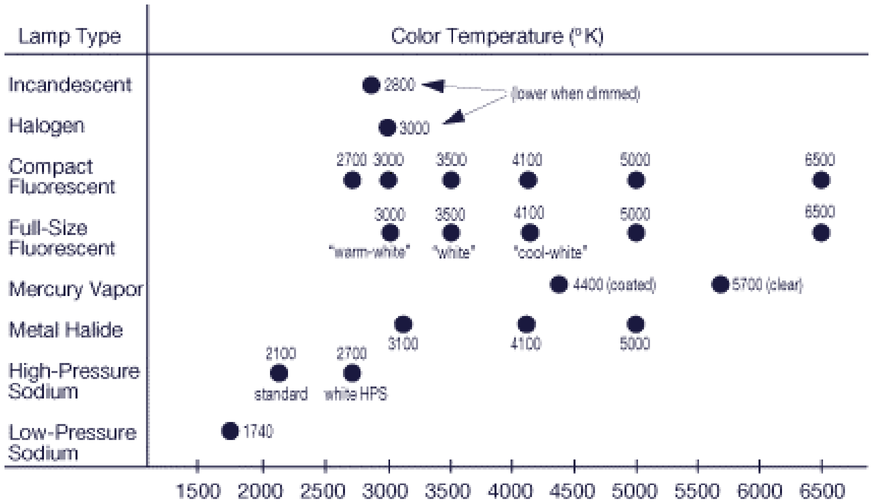

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Figure 6: Luminaire Components

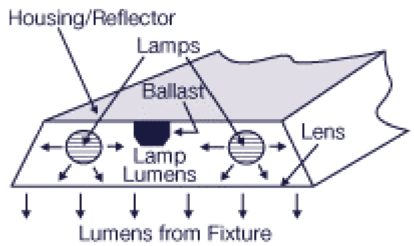

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Figure 7: Infrared Sensor Coverage Patterns

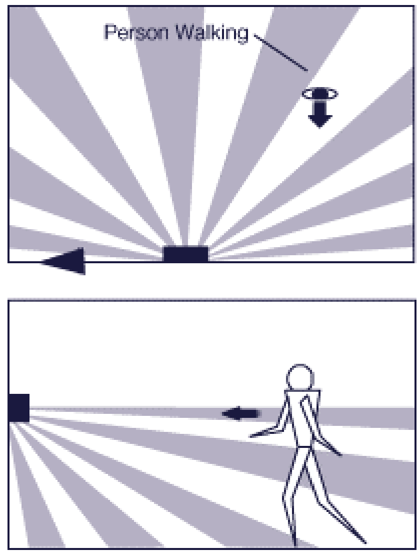

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Figure 8: Ultrasonic Sensor Coverage Patterns

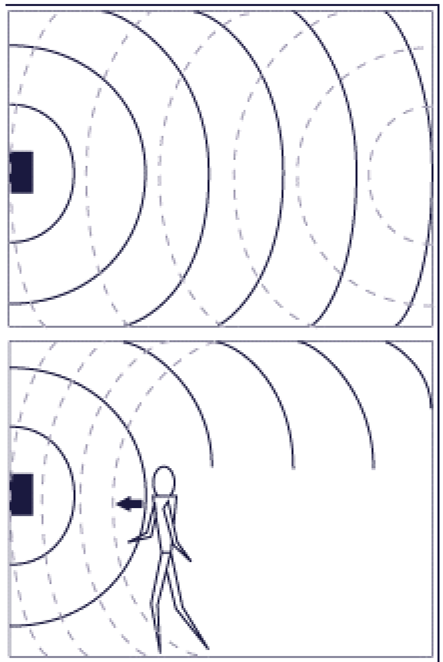

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Figure 9: Efficiency Loss Over Time

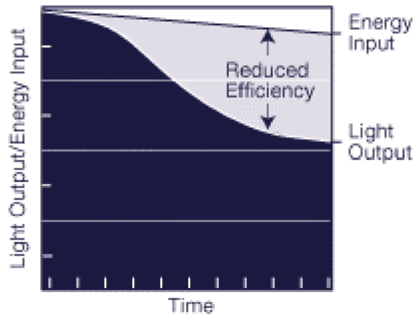

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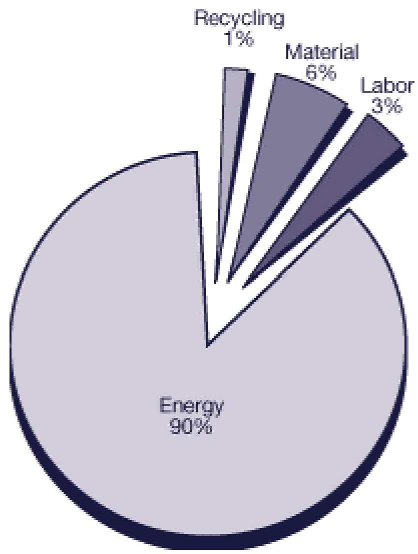
Figure 10: Fluorescent Lamp Life Cycle Cost



Assumptions:

(2) TB 32-W lamps
62-W system wattage (w/electronic ballast)
Electricity at 7¢/kWh
Lamps at $2.65 each
Relamp labor at $1.50 each (group relamping)
Lamp life at 20,000
Lamp recycling at $0.50 each

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